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Measurement of Aircraft Trajectory Prediction Accuracy of Air Traffic Decision Support Tools

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Abstract

The Federal Aviation Administration has sponsored the development of several ground-based decision support tools (DSTs) to aid air traffic controllers in managing aircraft separation. The underlying functionality of these tools is based on the prediction of the future flight paths, or trajectories, of aircraft; therefore, the overall performance of a DST depends directly on the accuracy of its aircraft trajectory predictions. This paper presents an example of the application of a novel sampling technique, called interval-based sampling, that compares recorded aircraft radar tracks with predicted aircraft trajectories to measure a DST's trajectory prediction accuracy.

Introduction

The Federal Aviation Administration (FAA) has sponsored the development of several ground-based air traffic management decision support tools (DSTs) to support en route and terminal air traffic controllers. A fundamental component of a DST's design is its trajectory modeler, which provides a prediction of an aircraft's anticipated flight path based on information provided to the DST. This information may include the aircraft's flight plan, preferential routing, altitude and speed restrictions, airspace geography, weather, aircraft performance characteristics, and pilot or Flight Management System procedures. The deviation between a predicted trajectory and the actual path of the aircraft has a direct effect on the overall accuracy of a DST.

Based on previous work on the accuracy of DST's [1,2,3,4], the FAA's Engineering and Integration Services Branch (ACT-250) at the William J. Hughes Technical Center developed a generic method of sampling aircraft trajectories for accuracy measurements. This technique, called interval-based sampling, has successfully been used to evaluate the accuracy of the User Request Evaluation Tool (URET), developed by MITRE's Center for Advanced Aviation System Development, and the Center TRACON Automation System (CTAS), developed by the National Aeronautics and Space Administration's Ames Research Center. [5] It is also being used for the formal accuracy testing of the

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URET Current Capability Limited Deployment system, which is the operational deployment of URET, a part of the FAA's Free Flight Phase One effort.

This paper first provides a brief overview of interval-based sampling, which is described in detail in Reference 6, and then presents an illustrative example of its application based on recorded track data from the Memphis Air Route Traffic Control Center (the ZME ARTCC) and trajectories generated by the URET Daily Use system.

Interval-based Sampling

In interval-based sampling the accuracy of a DST trajectory is defined by spatial errors measured between time coincident track and trajectory points, using a sign convention to indicate the direction of the error. These trajectory accuracy errors are identified as the longitudinal error, which represents the along track difference between track and trajectory, the lateral error, which represents the cross track difference, the horizontal error, which is the vector sum of the longitudinal and lateral errors, and the vertical error, which represents the altitude difference.

The tracks used in interval-based sampling are defined as a set of time-stamped three-dimensional position points. These track points are recorded by the en route Host Computer System approximately every twelve seconds. The trajectories are the predicted tracks of an aircraft generated by a DST, which may be represented by points that are equally spaced in time or by the way points at which the aircraft is predicted to change course. Since the trajectory accuracy errors require time coincident track and trajectory data, the track and trajectory points are interpolated to 10-second intervals, synchronized with the hour.

The trajectory accuracy errors are calculated for each aircraft by sampling each of the aircraft's track points in succession at a user-specified sampling interval (e.g., two minutes) until the end of the track is reached. At each sample time, the aircraft's trajectories are searched to find the most recently constructed trajectory for the aircraft. The accuracy errors are calculated at this sample time, which represents a zero look ahead time, and at a number of user-specified look ahead times in the future (e.g., 5, 10, 15, and 30 minutes).

Example of Accuracy Measurements

To illustrate the accuracy measurements a typical flight was selected from a Memphis ARTCC accuracy test scenario. Flight ABC1000 is an overflight through ZME airspace on a flight from a departure airport in the Kansas ARTCC (ZKC) to a destination airport in Atlanta ARTCC (ZTL). Its horizontal profile is given in Figure 1; its vertical profile in Figure 2.

At the start of the track the aircraft is climbing through 6400 feet to Flight Level 290, which is reached at 45370s (seconds) Universal Coordinated Time (UTC). The aircraft

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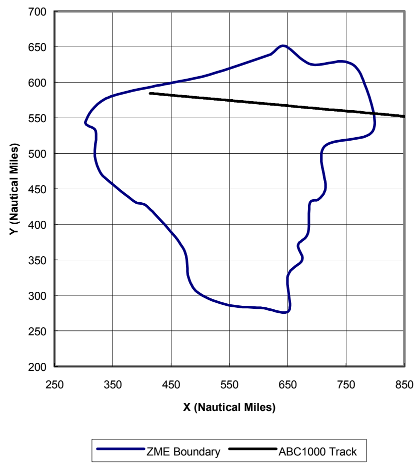
flies at Flight Level (FL) 290, descends to FL 270 at 46160s and continues at this altitude until 48320s, then descends to FL 210 and begins its final descent at 49020s. ZME hands off the aircraft to ZTL, the adjacent Center, at 48600s when the aircraft is in level cruise at FL 210. It exits the ZME airspace at 48800s while still in level cruise at FL 210.



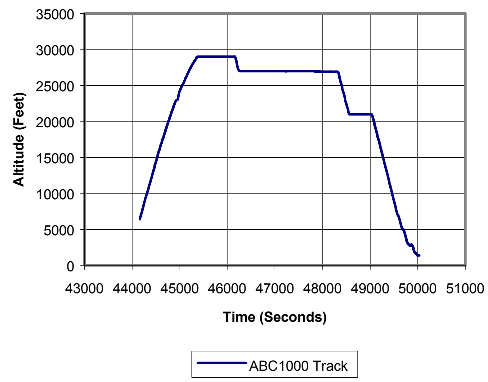


Figure 1: ABC1000 Track – Horizontal Profile

Figure 2: ABC1000 Track – Vertical Profile

The decision support tool in this example, URET Daily Use, generated 18 trajectories while the aircraft passed through the ZME airspace. Ten of the trajectories were sampled. The sampled trajectories are identified by the times in seconds they were generated (44156, 44576, 44841, …).

For this example, the aircraft's track data was sampled every two minutes. For each sample point, error measurements were made at the look ahead times of 0, 60, 300, 600, 900, and 1200 seconds. The first sample point is the first track report for ABC1000 in the scenario at 44160s. The current trajectory was built at 44156s. Samples were chosen at 44280, 44400, 44520, and up to 49800 seconds. For each sample time the active trajectory was selected. Next, the trajectory was compared to the track data at the sample time plus each of the five look ahead times.

The horizontal and vertical distances between the track and the trajectory are calculated at the measurement times. The horizontal error distance is split into two orthogonal components: the longitudinal or along track error and the lateral or cross track error. The sampling and look ahead procedure produced 224 measurement times. A subset of the error measurements made at these times is listed in Table 1. For this example, all of the lateral (cross track) errors between the aircraft track and the current trajectory are small. The longitudinal (along track) errors are up to several nautical miles. The largest longitudinal errors occur on the climb and on the descent. The largest longitudinal error on the climb is 15.2 nm (measurement time is 45720) with a look ahead time of 20 minutes and a trajectory age of 26 minutes. The largest longitudinal error on the descent is 18.4 nm (measurement time is 49380) with a look ahead time of 15 minutes and a trajectory age of 16 minutes. The large longitudinal errors are errors in time. The prediction of *where* the aircraft is going to fly are correct, but the prediction of *when* the aircraft is going to fly the route is in error.

Table 1. Trajectory Metrics for ABC1000

SAMPLE TIME	TRAJ BUILD TIME	LOOK AHEAD TIME	MEASUR TIME	HORZ ERROR	LATERAL ERROR	LONG ERROR	VERT ERROR	OUT BOUND FLAG	CLEAR FLAG
44160	44156	0	44160	0.388	-0.382	0.064	-16.667	0	0
44160	44156	60	44220	0.501	-0.365	0.343	-225.641	0	0
44160	44156	300	44460	0.749	-0.367	-0.653	-366.423	0	1
44160	44156	600	44760	4.159	-0.364	-4.143	-322.462	0	1
44160	44156	900	45060	7.239	-0.405	-7.227	2.842	0	1
44160	44156	1200	45360	11.510	-0.203	-11.508	-67.000	0	1
44280	44156	0	44280	0.655	-0.474	0.452	-264.103	0	0
44280	44156	60	44340	0.486	-0.448	0.188	-368.625	0	1
44280	44156	300	44580	1.944	-0.458	-1.889	-179.214	0	1
44280	44156	600	44880	5.684	-0.328	-5.675	-205.569	0	1
44280	44156	900	45180	8.503	-0.422	-8.492	-124.895	0	1
44280	44156	1200	45480	13.258	-0.328	-13.254	0.000	0	1
44400	44156	0	44400	0.591	-0.574	-0.140	-402.537	0	0
44400	44156	60	44460	0.749	-0.367	-0.653	-366.423	0	0
44400	44156	300	44700	3.372	-0.511	-3.333	-434.615	0	0
44400	44156	600	45000	6.475	-0.340	-6.466	70.501	0	1
44400	44156	900	45300	10.190	-0.367	-10.183	-567.000	0	1
44400	44156	1200	45600	14.025	-0.324	-14.021	0.000	0	1
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47880	46142	0	47880	0.748	-0.092	0.742	0.000	0	0
47880	46142	60	47940	0.817	0.018	0.817	-34.000	0	0
47880	46142	300	48180	1.210	-0.200	1.193	-100.000	0	0
47880	46142	600	48480	2.741	-0.327	2.721	-4167.00	0	1
47880	46142	900	48780	4.525	-0.275	-4.517	-2000.00	1	1
47880	46142	1200	49080	9.770	-0.256	-9.767	1029.24	1	1
. . . .									

The vertical prediction errors are caused by not knowing when altitude changes are going to take place and again by errors in time. The aircraft steps down in altitude twice during the flight before its final descent to its destination airport. The first six trajectories miss the first step down to FL 270; the first eight trajectories predict the start of the second step down to FL 210 but predict the incorrect leveling off altitude. The last two trajectories correctly predict the leveling off at FL 210 but are slightly off on predicting the top of descent point.

Not all six measurement times are made for every sample time since no measurements can be made when the sample time plus the look ahead time is greater than the end of the track or the end of the trajectory being measured.

All the accuracy measurements, processed track reports, and parsed trajectories are stored in a relational database. Utilizing this database implementation, the accuracy statistical analysis can exclude measurements when desired. For example, if the DST is predicting past the time of hand off to the next ARTCC, the measurement is flagged with a 1 and excluded in the statistical results. In Table 1's column, labeled "Out Bound Flag", a 1 identifies these measurements. In this example, handoff occurs at 48600 seconds. Measurements past that time are flagged accordingly. If the DST is predicting past an air traffic control directive, this measurement is also flagged and excluded for certain analyses. In Table 1's column labeled "Clear Flag", a 1 identifies these measurements. The aircraft receives a flight plan amendment to descend from FL 290 to FL 270 at 46142s and starts descending at 46160s. Any measurements made after 46142 on a trajectory built before 46142 are flagged with a 1 in the "Clear Flag" column. Table 1 shows that the large (greater than 1000 feet) vertical prediction errors are caused by predicting past an air traffic control directive.

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